THE

JOURNAL OF GEOLOGY

JULY-AUGUST, 1902

THE DEVELOPMENT OF SYSTEMATIC PETROGRAPHY IN THE NINETEENTH CENTURY.

Part II.[1]

Beginning of the microscopical era.— Having presented the state of systematic petrography up to the time when the polarizing microscope became the instrument of prime importance in the investigation of rocks, we now proceed to the study of the more recent schemes of classification, based upon the larger knowledge. For all systems thus far reviewed, it must be recognized that ignorance of the characters and relationships of many rocks rendered a comprehensive and logical scheme impossible. The frame work of system was necessarily constructed without full knowledge of the applicability of some of the factors employed. With the polarizing microscope and improved methods of chemical analysis this condition has now disappeared, and while the time may not be ripe for unbiased criticism it is plain that modern systems of classification must ultimately be judged with regard to the greater and almost perfect knowledge of the actual characters of rocks enjoyed by the authors of those systems. The responsibility for the choice of factors suitable for the construction of a comprehensive system and for a logical, consequent, and consistent application of those factors clearly increases with knowledge of the objects to be classified.

The microscopical study of rocks, continuing for nearly four

[1] Continued from p. 376.

decades with ever improving facilities and methods, has added a vast store of knowledge concerning the characters of these objects. Revelations concerning the composition of types long known have often been astonishing. The essence of rock structures has been made clear. The uttermost parts of the earth have been searched, and many new and interesting varieties have been discovered—not all in distant fields, but often close at hand. For new structures and new types, new terms have been proposed, and the nomenclature has thus expanded enormously. In the light of new discoveries, old conceptions have given way to new ideas, and the terms expressing them have yielded to new ones, or, in too many cases, the old nomenclature has been retained with new definitions. But while the last third of the nineteenth century may be termed the microscopical period of petrography, great additions to our knowledge of rocks were also made in this period on all older lines of study, and especially by quantitative chemical analysis and by investigations as to the modes of occurrence and the field relations of different rocks.

This review, which deals with system, must trace the application of new or revised principles to classification during this period of rapid addition to knowledge. It is perhaps quite natural that the greater part of the systematic advance was in partially worked out revisions of old schemes—grafting some new idea to the old trunk. It is also natural that the greatest work has been in the field to which the microscope has been particularly applied, so that at times petrography has been treated as though narrowed to the microscopical petrography of igneous rocks.

While the flood of microscopical rock studies was at its height, it was manifestly impossible for anyone to do more than to present the new information in comprehensive form, without finished attempt to apply it to the systematic arrangement of rocks. It is with this condition in mind that the important works upon microscopical petrography, issued in the decade 1870 to 1880, must be judged. Their actual effect upon the systematic science was, however, very great, from the mere fact

that they exerted a controlling influence over the usage of a multitude of workers.

Ferdinand Zirkel, 1873.—In 1873 appeared *Die mikroskopische Beschaffenheit der Mineralien und Gesteine*, by F. Zirkel. The systematic point of view occupied by this authority at this time is expressed in the following tabular analysis of his larger divisions of rocks:

A. Non-clastic rocks ("Nicht-klastische Gesteine").
  I. Simple ("Einfach").
  II. Composite ("Gemengt").
    1. Massive ("Massig").
      a. Feldspathic ("Feldspath-haltig").
      b. Non-feldspathic ("Feldspath-frei").
    2. Schistose ("Schieferig").
B. Clastic-secondary rocks ("Klastische-deuterogene-Gesteine").

Comparing this scheme with that of the *Lehrbuch der Petrographie*, we find that the microscope has convinced Zirkel that *crystalline* cannot be appropriately opposed to *clastic*. He also believes that *original* cannot be used for non-clastic rocks because they have been discovered to be at the present time in part composed of alteration products. He therefore falls back on a negative term, *nonclastic*, admitting that it is indefinite—"misslich." *Massive* is defined as *not schistose, in larger part granular*—"nicht geschiefert, zum grossen Theil körnig."

The work deals mainly with the *feldspathic, massive, composite, non-clastic rocks*. These are subdivided as follows:

I. Orthoclase rocks.
  1. With quartz.
  2. Without quartz, with or without plagioclase.
  3. Without quartz, with nephelite (or leucite).
II. Plagioclase rocks.
  1. With hornblende.
  2. With augite.
  3. With diallage.
  4. With hypersthene.
  5. With mica.
  6. With olivine.
III. Nephelite rocks.
IV. Leucite rocks.

The use of the soda-lime feldspars—oligoclase, labradorite, and anorthite, as factors in the subdivision of feldspathic rocks, found in the *Lehrbuch*, had been shown by the microscope to be an error, and it disappears without comment. The mineral composition of rocks is here applied to their classification in a qualitative way almost exclusively. Zirkel remarks: "To the non-feldspathic, non-schistose, composite rocks belong among others: eclogite, tourmaline rock, olivine rock, eulysite and saussurite-gabbro." Of these only three are described and within a compass of two pages.

The age distinction in classification of igneous rocks is freely characterized by Zirkel as unnatural and undesirable and it is not formally recognized in this work as it was in the *Lehrbuch*, yet he could not see his way to carry out the reform necessary to its rejection and retained in description many of the duplicate terms based on it.

Structure and *crystalline condition* were not given a defined rôle in Zirkel's new system, but in practice the granular, porphyritic, fluidal and glassy forms were distinguished.

A. von Lasaulx, 1875.—The *Elemente der Petrographie*,[1] by A. von Lasaulx, issued in 1875, is another attempt to utilize the results of microscopical study of rocks in their classification and description. Von Lasaulx believed that since there are no true rock species, and since transitions in all directions are most common, classification must consist in the establishment of *types*, about which should be grouped the intermediate kinds of rocks. He announced as his guiding principle that rocks must be classified upon the basis of simple, definitely known and easily recognized, morphological properties. Genetic criteria did not seem to him applicable because always more or less hypothetical and in some cases entirely so. He, therefore, discards the primary classification of rocks on genetic principles, advocated by von Cotta and others, and returns to von Leonhard's elementary division into *Simple*, *Composite* and *Clastic* rocks, omitting the *Apparently simple* class as no longer necessary.

[1] *Elemente der Petrographie*, Bonn, 1875, pp. 486.

The morphological characteristic of rocks chosen by von Lasaulx as most applicable to the systematic subdivision of the classes mentioned was the degree or distinctness of crystallinity, which is surely the most variable of all their properties, and hence least adapted to the formation of well-defined groups. The major divisions formed by von Lasaulx are as follows :

Simple Rocks :

- A. Non-crystalline (amorphous) or semi-crystalline.
- B. Crystalline granular.
  - *a.* Really simple.
  - *b.* Rocks forming transitions to Composite group through the appearance of vicarious constituents (*e.g.*, amphibolite, serpentine, etc.).

Composite Rocks :

- A. Massive.
  - *a.* Amorphous, glassy (obsidian, etc.).
  - *b.* Semi-crystalline (including vitrophyres).
  - *c.* Crystalline.
    - 1. With abundant glassy base (basalt, etc.).
    - 2. With microaphanitic more or less individualized groundmass.
      - *aa.* Groundmass alone (felsite, etc.).
      - *bb.* True porphyries (felsite-porphyry, etc.).
    - 3. Rocks which are almost completely crystalline, mainly pseudo-porphyritic, etc. (phonolite, hornblende-andesite, etc.).
    - 4. Crystalline granular.
      - *aa.* Feldspathic (granite, etc.).
      - *bb.* Non-feldspathic (Greisen, eclogite, etc.).
- B. Stratified Rocks :
  - *a.* Feldspathic (gneiss, etc.).
  - *b.* Non-feldspathic (mica-schist, etc.).

Clastic Rocks :

- A. Semi-clastic (clay slate, kaolin, tuff, etc.).
- B. Purely clastic.

Mineral composition is applied as a factor to produce the commonly recognized rock types within these groups. It will be noted that many of the divisions above mentioned are not only quite indefinite but they are, also, inconsequent. Thus, three out of four divisions of *crystalline massive* rocks are but *partly* crystalline.

Meteorites are described by von Lasaulx in an appendix.

Concerning this treatment he remarks that it is the first time that cosmic rocks have been given a place in a text-book of petrography, but that it seems useful, for purposes of comparison, to have them described in the same work with the terrestrial rocks.

H. Rosenbusch, 1877.—Another important summary of the results of the microscopical investigation of rocks appeared in 1877, under the title *Mikroskopische Physiographie der massigen Gesteine*, by H. Rosenbusch. There was in this work but slight discussion of principles of classification, and the only new factor of note in the system used is the idea expressed in the title, which requires some explanation. All rocks were divided into two classes:

I. Massive rocks ("Massige Gesteine").
II. Stratified rocks ("Geschichtete Gesteine").

A class of Metamorphic rocks was not considered feasible.

"Massive" and "stratified," as used by Rosenbusch in this connection, do not refer to rock textures, as one might suppose from the historic use of the terms; for this primary division was avowedly intended to express an idea, first brought out by Lossen (which will be referred to more fully in a later section of this review), that the most important relation of rocks is the formal one to the earth sphere. Rocks may be considered as having been formed, either at the surface under the influence of gravity, in more or less concentric shells or strata, or, in eruptive bodies of irregular shape and position not determined by gravity. Under this conception all rocks are either stratified or massive. Massive rocks in this sense are also eruptive rocks, but Rosenbusch chose to use the former term in systematic petrography because free from the genetic conception involved in the latter. In view of the evolution of this master's ideas, presented in later works, his language will be quoted:[1] "The former name is to be preferred because it refers only to an undeniable form of

[1] "Der erste Name ist vorzuziehen, weil er sich lediglich auf eine unläugbare Erscheinungsform bezieht und keinerlei irgendwie geartetes Präjudiz über die genetischen Verhältnisse involvirt."

occurrence, and involves no possible prejudice concerning genetic relations."

The controlling criteria in the further construction of Rosenbusch's scheme will be apparent from the following partial tabular statement :

Massive rocks.
- A. Orthoclase rocks.
  - *a*. Older.
    - I. Quartzose.
      - 1. Granular = Granite Family.
      - 2. Porphyritic = Quartz porphyry Family.
      - 3. Vitreous = Felsite-Pitchstone Family.
    - II. Quartz free (3 families similar to those above).
  - *b*. Younger.
    - I. Quartzose.
      - 1, 2. Granular or porphyritic = Liparite Family.
      - 3. Vitreous = Family of the acid glasses.
    - II. Quartz free (with families as above).

The other large groups are the following :

- B. Orthoclase-Nephelite, or Orthoclase-Leucite rocks.
- C. Plagioclase rocks.
- D. Plagioclase-Nephelite, or Plagioclase-Leucite rocks.
- E. Nephelite rocks.
- F. Leucite rocks.
- G. Non-Feldspathic rocks. Of the Non-feldspathic rocks Rosenbusch remarked[1] that they were all rich in olivine, and might therefore be called *Olivine rocks*.

Each of these groups has Older and Younger divisions, and, within these, families, established in a manner similar to that given for the orthoclase rocks.

In this arrangement *mineral composition* is used, as in Zirkel's system. The *age distinction* is applied without discussion. *Texture* is given a prominent rôle, and *chemical composition is not used*.

Fouqué and Michel-Lévy, 1879.—The first effects of the microscopical study of rocks upon petrographic system in France may be seen in the *Minéralogie micrographique*, by F. Fouqué

[1] "Sie sind sämmtlich reich an Olivin, daher kann man sie kurz als Olivingesteine bezeichnen."

and A. Michel-Lévy, which was published in 1879. While presented as an "Introduction à l'étude des roches éruptives françaises," there is in this work some discussion of principles of classification, and a tabular view of the scheme in use by the authors. Although the system in question has not had much influence except in France, it is of interest from certain new and peculiar conceptions which are given classificatory value in it.

It is first to be noted that Fouqué and Michel-Lévy abandon almost entirely the system of Cordier. Although affirming that rocks are simply the most abundant natural associations of minerals ("les roches ne sont autre chose que les associations minérales naturelles le plus fréquentes"), they proceed to their arrangement under the stated principle that a rational classification of rocks in general must be based upon the following three fundamental characters, namely: (1) The mode of formation; (2) the geological age; (3) the specific mineral properties. The last named character comprises: (*a*) the nature of the integrant minerals; (*b*) the structure of the rock.[1] By the application of the first factor they separate eruptive rocks from those deposited as sediments or as vein filling. By the factor of geological age (the applicability of which is not discussed) they distinguish clearly—"nettement"—between pre-Tertiary and Tertiary or post-Tertiary rocks. It is believed that the same types occur in both groups, following approximately the same order of eruption, with predominance of basic rocks and a tendency to the vitreous condition in the most recent occurrences. In these respects the new French system is practically like others which have been reviewed, but in the use of *structure* and *mineral composition* for the main framework of their system, Messrs. Fouqué and Michel-Lévy apply certain peculiar conceptions requiring some analysis.

Considering that in practically all eruptive rocks there have been two (or more) distinct periods of formation of the primary

[1] "Un classement rationel des roches, en général, doit s'àppuyer sur les trois caractères fondamentaux suivants: 1° le mode de formation; 2° l'âge géologique; 3° la spécification minéralogique. Ce dernier caractère comprend: (*a*) la nature des minéraux intégrants; (*b*) leur structure d'association (structure de la roche.)"

mineral grains, these authors proceed to give a strangely artificial weight to the products of the second period, both in definitions of structure and in classifying rocks by mineral composition. The structures of eruptive rock applied in classification are brought under two groups: "structures granitoïdes" and "structures trachytoïdes." The essential difference between the two is conceived to be that in the granitoid the grains of the two periods of consolidation resemble each other, because of similar conditions of consolidation in the two periods, while in the trachytoid structure there is a marked difference between the two products as a result of changed conditions in the later period. In the rocks commonly called granular it is thought that two generations of mineral grains of approximately the same formal character may usually be recognized. Where no distinction can be made it is rather paradoxically assumed that the grains all belong to the *second* period. But it is to be noted that without this assumption the scheme of Fouqué and Michel-Lévy, as it stands, could not classify such a rock. Porphyries in which the groundmass is granular are, from that fact, classed with perfectly granular rocks.

Under the granitoid group of structures three varieties are recognized: (1) Granitoid proper, in which each individual grain has approximately equal dimensions in all directions, variation in size being disregarded; (2) pegmatoid, the regular or graphic intergrowth of two minerals of simultaneous crystallization; (3) ophitic, characterized by elongated feldspar crystals, and forming a transition to the microlitic structure.

The trachytoid group of structures has likewise three varieties: (1) *Type pétrosiliceux*, characterized by bands of minute spherulites and the presence of the mysterious substance petrosilex or microfelsite; (2) *type microlithique*, characterized by microlites of feldspar, and of other minerals; (3) *type vitreux*, characterized by predominance of amorphous substance.

In explaining the microlitic type the authors point out that their synthetic experiments prove that such microlites are products of *pure igneous fusion*, indicating to them a fundamental

difference between the trachytoid and the granitoid structures, since they believe that certain mineralizing agents ("agens minéralisateurs") are necessary to the latter development.

This view of rock structures makes the shape of the mineral grains all important and casts aside the formal relationship prominent in the porphyritic structure as of little value. The equidimensional *grain* and the elongated *microlite* are placed in fundamental opposition to each other.

The mineralogical composition of rocks is applied for their classification in a qualitative way, similar in some respects to that adopted by the German petrographers, but with the all important modification that *only the minerals of the second period of consolidation are considered.* Such a principle may be designated as subjective, extremely unnatural and highly artificial. There is in this system no attempt to express the chemical composition of the rock in terms of its minerals, for in some cases all the minerals of a rock are used in its classification, where there was no *first* period of consolidation, and in other cases only a small portion of the constituents, as in porphyries with abundant phenocrysts and microlitic groundmasses. Since in porphyries this portion of second consolidation bears no definite quantitative relation to the mass as a whole it must often happen by this system that rocks of widely different chemical composition will be brought together and, conversely, that rocks of the same chemical character and even of the same magma will at times be separated. For example, certain intrusive quartzose hornblendic diorite-porphyries of the Rocky Mountain region, in which hornblende and plagioclase are developed entirely in phenocrysts, would fall among the microgranulites while their granular equivalents would be quartz-diorites. It is also clear that all but granular rocks would be classified in this scheme by their most obsure constituents, often to the neglect of every prominent megascopic character, and systematic petrography would become purely a microscopical science. It is interesting to recall at this point the principle announced by these authors and quoted above that a rational classification of rocks must be

based upon the "fundamental characters" whose application has been reviewed,

In practice, Fouqué and Michel-Lévy give the first importance to the colorless constituents, quartz, feldspars, feldspathoids, etc., to produce series within which the ferromagnesian minerals are used to make subdivisions. The existence of certain phenocrysts is recognized, in the naming of rocks, in a few cases only.

The petrographic system for eruptive rocks elaborated by Fouqué and Michel-Lévy in 1879 has remained the system of France to the present time, with but slight change.

In 1889 Michel-Lévy compared the results of their system with those of the Rosenbusch system, soon to be discussed, in a work entitled *Structures et classification des roches éruptives.*[1] This

[1] Paris, 1889, pp. 93.

discussion presented no new propositions of note excepting a plan of expressing the structure and mineral composition of any given rock by a formula. The principles which must govern the classification of eruptive rocks are concisely stated as follows:

> It is neccessary to base the classification and nomenclature of rocks upon positive facts, independent of all hypothesis. Modern petrography possesses the means to accomplish this end, since the principal structures or modes of association of the minerals are well known and the minerals themselves may be determined with precision. It is, then, exclusively structure and mineral composition which must be relied upon in the classification and nomenclature of rocks.[1]

It is to be remarked, once more, that chemical composition is not taken into account by Michel-Lévy, either directly or indirectly, since the partial mineral composition used by him in classification is clearly not an expression of the chemical composition of the magma nor of any definite part of it. The substance classified is not the rock but merely that variable portion

[1] "Notre conclusion, ... est qu'il faut baser la classification et la nomenclature des roches sur des faits indépendants de toute hypothèse, et de nature positive. La pétrographie moderne dispose de moyens suffisants pour atteindre ce but sans hésitation: on est d'accord sur les principales structures d'association des minéraux des roches; on sait déterminer ces minéraux avec précision. C'est donc *exclusivement* sur la structure d'association et sur la composition minéralogique que nous persisterons à nous appuyer pour classer et nommer une roche." *Loc. cit.*, p. 87.

of the rock which the investigator judges was in a fluid or pasty condition at the beginning of the second period of consolidation —the "pâte."

Samuel Allport.—During this period in which Zirkel, Rosenbusch, Fouqué and Michel-Lévy were formulating more or less distinct advances in systematic petrography, the English students of rocks made but slight positive contributions in this direction. The condition of the science may be best appreciated by reference to the various short discussions of principles of classification by Samuel Allport. This careful investigator often pointed out the fallacy of the age distinction, so clearly illustrated by the long-known ancient lavas of the British Isles, and also the importance of Judd's discovery of the intimate relationship of coarsely crystalline and volcanic rocks. This was cited to disprove the idea that a sharp line could be drawn between the Plutonic and Volcanic rocks. But Allport considered it premature to suggest any great changes either in classification or nomenclature.

Clarence King, 1878.—In America no original contributions to systematic petrography were made prior to the microscopical period. The earliest use of the knowledge gained in that period was probably by Clarence King,[1] whose appreciation of its value led to the report upon the Microscopical Petrography of the 40th Parallel rocks by Zirkel, and who, also, applied certain supposed facts resulting from microscopical research in his own discussion of the classification of volcanic rocks. The proposition referred to has had little influence upon petrographic system, but has a certain importance from the standpoint of this review as illustrating again the dangers of applying genetic ideas in the classification of igneous rocks.

King accepted the law of Bunsen and the law of succession of volcanic rocks advocated by von Richthofen, which have been stated. He also considered that "a sharp line is to be drawn between the so-called Plutonic rocks and the true igneous ones." The microscopical studies of which he had knowledge led him

[1] Report of the Geological Exploration of the Fortieth Parallel, I. *Systematic Geology*, pp. 705–25, Washington, 1878.

to the strongly stated conclusion that "all the volcanic rocks show abundant evidence of fusion in the presence of glass base and glass inclusions, while the group which is typified by granite never shows the slightest trace of the effects of fusion." All known characters of plutonic rocks are interpreted as proving them to be extreme products of the metamorphism of sediments. After discussion of the cause of generic differences of volcanic rocks, in which certain new hypotheses concerning magmatic differentiation are developed, King proposes the following systematic arrangement for the family of volcanic rocks, including therein all believed to be of truly igneous origin:

Genera.—(1) Propylite; (2) Andesite; (3) Trachyte; (4) Neolite. Expressions of time, according to von Richthofen's law of succession, and of depth owing to secular refrigeration.

Species.—Expressions of chemical differentiation by specific gravity of mineral ingredients, grouping under the law of Bunsen.

Three species only were recognized under each genus, representing respectively the quartz, biotite or hornblende, and pyroxene-bearing forms.

Varieties.—Expressions of range of texture according to predominance of secreted crystals, groundmass, or base.

M. E. Wadsworth, 1884.—Under the title *Lithological Studies; A Description and Classification of the Rocks of the Cordilleras*, M. E. Wadsworth published, in 1884, the first part of a projected comprehensive work, intended to present a new classification of rocks. This first part was devoted to a discussion of principles and the beginning of the descriptive portion. Wadsworth denounced all existing systems as highly artificial, and stated, as the basis of his own more natural system, the belief that "the older rocks now classed as distinct species are rocks that were once identical with their younger prototypes." "The order [of his system] will be to pass from the glassy to the most perfectly crystalline state; from the least altered to the most altered; from the most basic toward the most acidic; from the non-fragmental to the fragmental or clastic." He plunged at once into a description of ultrabasic rocks, without explaining the

proposed application of his asserted principle to the construction of a system, and no further portions of the projected work have appeared. It is plain that the basis of Wadsworth's conception is contrary to known facts of petrogenesis. A direct contribution to petrographic system is afforded by the proposition made by Wadsworth to group terrestrial and meteoric masses together, applying to them a single system and nomenclature. The descriptive portion of the published work is, in fact, mainly occupied with discussion of meteorites rich in iron. Wadsworth thus goes a step further than von Lasaulx, who treated meteorites in an appendix to his discussion of terrestrial rocks (p. 455).

It is hoped that the trend of the evolution of systematic petrography during the earlier portion of the microscopical era has been fairly indicated in the preceding pages. The tendency, most natural under the circumstances, was to overestimate the systematic importance of some of the discoveries made through the microscope, and to slight other, more fundamental, properties or relations of rocks. Many new rock names were proposed and usage became fixed and extended in directions where it had never been well grounded. Protests against the tendency of the times were numerous, and especially from the geologist's standpoint. Many of these protests were of little influence, because based upon imperfect appreciation of the situation; others were far too conservative in spirit.

J. D. Dana, 1878.—As an example of the conservative geologist's view at this time may be cited the discussion of petrographic system by J. D. Dana in an article published in the *American Journal of Science* in 1878 under the title "On some Points in Lithology."[1] This article refers to the *Mikroskopische Physiographie* of Rosenbusch, and to other recent works, and may be taken as expressing the author's view of petrography at the stage of its development just reviewed.

Lithology, according to Dana, is charged with the descrip-

[1] *Amer. Jour. Sci.*, 3d ser., Vol. XVI, p. 335, 1878.

tion and naming of rocks. It has "to note down their distinctions in such a manner as shall best contribute to the objects of geology." "From granite down they [rocks] are with very few exceptions mixtures of minerals, as much so as the mud of a mud bank." "Strongly drawn lines exist nowhere." "Rocks are therefore of different *kinds*, not of *different species;* and only those mixtures are to be regarded as *distinct kinds* of rocks which have a sufficiently wide distribution to make a distinct name important to the geologist."

Dana discusses the bases of classification adopted by petrographers of this time, such as age, structure, and contents in certain minerals, and objects to most of them as trivial or wrongly used. He then proposes an arrangement of the "Crystalline rocks, exclusive of the calcareous and quartzose kinds," under the following groups :

I. Mica and potash feldspar series — Granite, gneiss, mica schist, trachyte, etc.

II. Mica and soda-lime feldspar series — Kersantite, kinzigite, ditroite, phonolite, etc.

III. Hornblende and potash feldspar series — Syenite, hornblende-schist, foyaite, etc.

IV. Hornblende and soda-lime feldspar series — Diorite, andesite, euphotide, etc.

V. Pyroxene and potash feldspar series — Amphigenite.

VI. Pyroxene and soda-lime feldspar series — Augite-andesite, norite, dolerite, etc.

VII. Pyroxene, garnet, epidote, or chrysolite rocks, containing little or no feldspar, lherzolite, dunite, garnetite, etc.

VIII. Hydromagnesian and aluminous rocks. Chloritic, talcose, and other schists, serpentine, etc.

While Dana does not refer in this article to the broader grouping of rocks, it appears, from various editions of his *Manual of Geology*, that he uses mode of origin to distinguish the three great classes — Igneous, Sedimentary, and Metamorphic — in discussing that question; but, in arranging rocks for description, he abandons that principle, and makes another division as more convenient. Convenience of presentation, and not expression of natural relations, is really the object of Dana's arrangement. It

is, therefore, not strictly a petrographic system. In the second edition of the *Manual* (1874), igneous and metamorphic groups were separated in description; but, probably for the reason that such a course involved the splitting up of granitic, syenitic, and other types supposed to be metamorphic in part and eruptive in part, Dana had, in 1878, evidently adopted the arrangement found even in the last edition of the *Manual* (1895), whereby *crystalline* and *fragmental* were opposed to each other, as by Zirkel in 1866.

Dana was never able to adopt the modern petrographic systems, founded so largely upon erroneous assumptions, like the age distinction among igneous rocks, or upon genetic views with which he was not in accord, and contented himself with an arrangement of convenience. The main features of this order of description appearing in the *Manual of Geology*, 1895, are seen from the four primary groups under which all rocks were treated:

1. Limestones, not crystalline.
2. Crystalline limestones.
3. Fragmental rocks, not calcareous.
4. Crystalline rocks.

The crystalline rocks were described under five heads:

I. Siliceous rocks, or those consisting mainly of silica.
II. Rocks having alkali-bearing minerals as chief constituents.
III. Saussurite rocks.
IV. Rocks without feldspar.
V. Hydrous magnesian and aluminous rocks.

The second group was divided nearly as in the proposition of 1878, above cited. This resulted in bringing together such unlike things as granite, greisen, minette, slate, agalmatolite, porcelain jasper, obsidian, etc., in the "Potash Feldspar and Mica Series."

Karl A. Lossen.—Among other protests raised by geologists against the tendency to treat rocks fom the microscopist's alleged narrow standpoint, one of the more philosophical discussions had an acknowledged effect making it worthy of notice; namely, that by Karl A. Lossen, himself a petrographer of dis-

tinction, yet in first degree a geologist, prominent upon the Prussian geological survey.

The views held by Lossen were repeatedly expressed, and were summed up in a discussion of principles entitled *Über die Anforderungen der Geologie an die petrographische Systematik.*[1] The "demands" here forcibly expressed are based upon the idea that, *because the rock is a geological body, the geological relations of rocks must be recognized as petrographical relations.* Of all the geological relations of rocks Lossen selected that which seemed to him the most important, and claimed that that principle should be used as the primary factor in petrographic classification. The relation of rock masses to the earth sphere appealed to Lossen as all important, and on that criterion all rocks were considered as *stratified* or *massive*. Stratified rocks were defined as those accumulated upon the earth's surface under the controlling influence of gravity, causing them to assume in some degree the form of concentric strata normal to the radius of the earth. The material of massive or eruptive rocks, on the other hand, was viewed as having been forced from the depths directly against the influence of gravity, consolidating like a casting, under the control of surrounding conditions. Surface lavas, spreading out in sheets, while controlled largely by gravity in their formal relations, were referred by Lossen to massive rocks, because possessing the resemblance to a casting from one pouring, and not as built up by successive additions, layer upon layer. It will be seen that the molten condition of magmas was actually a leading factor in Lossen's idea, although the avowed intention in using *eruptive* as an alternative for *massive* was to express the force opposed to gravity, and not the molten state which rendered them susceptible to that force.

Lavas are not the only rock masses difficult of consistent treatment under Lossen's principle. Pyroclastic tuffs were considered as illustrating the fact that "das Ineinandergehen zum Wesen der Gesteinsnatur gehört." Lossen confessed, further, that rocks of the first crust of the earth, according to the nebu-

[1] *Jahrbuch der k. pr. geol.* Landesanstalt, 1883, p. 486.

lar hypothesis, would necessarily be separated from his eruptive class, but he considered this point immaterial because he doubted whether any such rocks were known. Metamorphic rocks are of such diverse origin and present such difficulties to the systematist that Lossen considered it inadvisable to treat them as a distinct class.

In this discussion by Lossen, as in the majority of those emanating from geologists, no appropriate distinction is made between the rock mass as a formal unit and the material within it, the rock proper. The primary division of Lossen is one of rock masses, not of rocks. The consideration of the form and position of these masses with regard to the controlling influence of gravity or the opposing eruptive force, leads to only one of many ways in which the geologist must classify rock bodies. Other elemental subdivisions of the same bodies are necessary. The geologist is, indeed, obliged to make and discuss all such fundamental distinctions. The petrographer, on the other hand, should not only be at liberty to select, but, in order to secure logical excellence for his system, *must* choose, as his primary principle, that one most closely connected with the factors which he has adopted for use in the further construction of the systematic arrangement of rocks. It is clear that all igneous rocks, those produced by the consolidation of molten magmas, possess, from this origin, material properties most useful in their detailed classification. If arrangement by a certain characteristic due to this origin is desired, it matters not where the rocks occur in the earth. They may belong to the primeval crust, or form injected masses of whatever size, shape, or attitude, or appear on the surface in lava streams. If it was mode of origin, not formal relations to the earth, which gave igneous rocks the common characters used in their systematic arrangement, then mode of origin is logically the principle to be used by the petrographer to bring them into one grand division.

H. Rosenbusch, 1887.—As has been mentioned, the force of Lossen's claim, as made in earlier publications, was admitted by H. Rosenbusch, in the first edition of his *Mikroskopische Physio-*

graphie der massigen Gesteine, "massig" being used in the sense explained by Lossen, and not in that of textural condition. In the second edition of this widely-used handbook, which appeared in 1887, Rosenbusch repeated his approval of Lossen's proposition, and in the revision of his petrographic system further emphasized geological occurrence as a factor of prime classificatory value for eruptive rocks. The great changes in system found in this volume make it practically a new work, but a detailed statement of its scheme seems unnecessary since all petrographers may be assumed to be familiar with it.

In the decade since the appearance of the first edition, Rosenbusch effected a complete change of systematic base in some important respects, the reasons for which are given in the preface. He now considers rocks as the documents in which the history of the earth is written, and petrography, as the science which teaches us how to decipher those documents, becomes to him *a historical and not a descriptive science*. To quote his declaration:

> The recognition of these relations made the new edition of this book practically a new work. Its end will have been achieved if I have succeeded in procuring for this fundamental conception a general acceptance, and have demonstrated that rock structure affords the safest and most productive means for the construction of a natural system of rocks.[1]

A natural system of rocks must therefore be historical, *i. e.*, genetic. Plainly the logical analysis of the broad science of rocks presented by Naumann was either forgotten or ignored by Rosenbusch.

With this statement of controlling principles in mind, one involuntarily recalls that in the first edition of the *Mikroskopische Physiographie* the rocks to be discussed were designated *massive* in preference to *eruptive* because the former term was considered free from expression of any genetic idea. In this second edition, while advocating the genetic basis of classifica-

[1] "Die Erkenntniss dieses Verhältnisses machte die neue Auflage dieses Buches zu einer Neubearbeitung. Der Zweck derselben wird erreicht sein, wenn es mir gelungen ist, dieser Grundanschauung eine allgemeinere Anerkennung zu verschaffen und darzuthun, dass die Gesteinsstructur das sicherste und ausgiebigste Mittel zum Aufbau eines natürlichen Systems der Gesteine an die Hand giebt."

tion as all important, Rosenbusch retains the group term *massive*, yet in both works it is clearly the igneous origin which is first in mind and which is recognized as of prime importance in producing rock structure, chosen as the leading factor in constructing the new system.

After having stated his belief that rock structure is the best basis of classification of "massive rocks" Rosenbusch proposed to divide them into three groups: (1) Deep-seated rocks ("Tiefengesteine"), (2) Dike rocks ("Ganggesteine"), and (3) Effusive rocks ("Ergussgesteine"). The critic is obliged to point out that this proposition is inconsequent, for not only is structure not expressed in the terms chosen, but another distinct factor is expressed, namely, mode of occurrence. The further development of Rosenbusch's scheme makes it clear that he did not intend to emphasize the actual facts of geological occurrence, plainly as he stated them, but rather to express in this way his conception of the genesis of structure. Recognizing that different structures result from the consolidation of a given magma according to the attendant conditions, Rosenbusch selected the geological factor appearing to him of greatest influence among many conditions and made that the expressed basis of structural classification. Since simplicity and logical directness are surely of utmost importance in systematic constructions the unnecessary indirectness of this proposition may be designated a fatal weakness. Furthermore, the geologist is warranted in objecting to it because the expressed division of igneous rocks is one which he has used in the past and must use in the future, in its literal and appropriate sense, quite apart from the idea hidden in the terms of Rosenbusch's system.

To the above noted criticisms of Rosenbusch's first application of structure in classification must be added another, based upon the fact that the division of *Dike rocks* was not in reality provided for rocks occurring in dikes, but for a group of rocks for which Rosenbusch assumed a certain genesis. An hypothesis of magmatic differentiation and assumptions of limited occurrence and of characteristic structure are all involved in the dis-

crimination of the group named "Dike rocks." In this light this group is certainly not co-ordinate with the other two of the same rank as defined.

In the subdivision of the three classes of "Massive rocks" Rosenbusch applied mineral composition as a factor, producing Families. The quantitative composition, either chemical or mineral, received no expression, so that, for example, anorthosite and the most highly pyroxenic gabbro or norite are found together in the gabbro family. Moreover in the porphyritic Dike rocks only the phenocrysts are considered in determining the systematic position of a given rock. Thus a porphyry having the chemical composition of a granite is referred to syenite-porphyry in case its excess of silica chances to be confined to the groundmass, while had quartz phenocrysts been present it would have been called granite-porphyry. In the Effusive rocks, Rosenbusch hesitates to apply the same rule consistently. The families of these rocks are defined in very general terms as the "equivalents" of certain granular rocks and described as containing certain phenocrysts in a groundmass of variable appearance.

As in the earlier system, all feldspar-free rocks of the deep-seated class are united as Peridotites. The peculiar character of the Dike rocks as a division not co-ordinate or co-extensive in range with the Deep-seated or Effusive rocks appears in the fact that mineralogical groups corresponding to the granites, syenites, and diorites, only, are recognized.

Geological age is acknowledged by Rosenbusch to have been assigned a higher value in classification than belongs to it, but it is retained, in the Effusive class, and the use of duplicate terms perpetuated.

H. Rosenbusch, 1896.—The third edition of the "*Mikroskopische Physiographie der massigen Gesteine*," issued in 1896, contains no essentially new systematic features. The principles above set forth are reaffirmed, and, save for the elaborated discussions of magmatic differentiation, which show more plainly than in the preceding edition the strong influence of hypo-

thetical considerations in giving form to this system, there is little of note to comment upon in this place. In discussing the essential characters of the three groups of Dike rocks, Rosenbusch brings out more forcibly than before the genetic idea really lying at the base of the distinction of the Dike rock class. In connection with the discussion of the Dike rocks it is suggested that a further class may be necessary to include the intrusive rocks of sheets and laccoliths which seem to him to possess distinctive structures.

That the system of Rosenbusch does not result in a consistent and logical classification of igneous rocks is abundantly illustrated by numerous instances, many of them freely acknowledged by the author. The family of the diabase rocks furnishes one of the most notable cases. In 1887 these rocks were classified with the deep-seated rocks, although many of them were known to be effusive; in 1896 the same rocks are placed with the effusives, with the statement that many are intrusive. Placed in the effusive class, they are acknowledged to be partly of older and partly of younger age, but no age distinction is thought to be practicable.

Justus Roth, 1883.—Shortly before Rosenbusch issued the second edition of his *Physiographie*, there appeared a complete systematic discussion of rocks by Justus Roth, in the second volume of his *General and Chemical Geology.*[1] Petrography is defined by Roth as the science of the mode of origin, constitution, and alteration of rocks; *i. e.*, the petrology of many English and American writers. In introducing the systematic descriptive part of the subject, Roth remarks: "The difficulty in constructing a system of rocks is completely expressed in the term *aggregate*, and thereby all recourse to genera and species is prohibited."[2] From the nature of rocks and the conditions of

[1] *Allgemeine und chemische Geologie;* Zweiter Band, "Petrographie" (Berlin, 1883–1885), pp. X + 695.

[2] "Die Schwierigkeit der Systematik der Gesteine ist durch die Bezeichnung Aggregat vollständig ausgedrückt und damit alle Anlehnung an Gattungen und Species ausgeschlossen," *loc. cit.*, p. 41.

their origin, he thinks that every system must so largely represent individual opinion that probably no one system can ever receive universal recognition.

The systematic arrangement of Roth is, in its general outline, as follows:

A. Rocks composed essentially of minerals.
   I. Plutonic (consolidation products of molten magmas). Free from fossils, composed of minerals or substance chemically like a mineral aggregate.
      1. Eruptive. (Breaking through other rocks.)
         a. Pre-Tertiary.
         b. Post-Cretaceous.
            Appendices to *a* and *b* contain rocks produced by weathering. Tuffs.
      2. Crystalline schists.
         Appendix-Weathering products.
   II. Neptunic.
      1. Partly fossiliferous; composed of minerals and of the products of the decay, decomposition, and attrition of minerals.
         a. Precipitates from solution.
         b. Deposits from suspension.
      2. Clastic, composed of rock fragments.
B. Rocks composed essentially of organic remains.
C. Products of contact metamorphism.

It will be observed that the ancient crystalline schists are regarded as the primary crust of consolidation of the earth.

The geological factors of origin, relations, or age, are variously applied in the construction of this scheme, and in constitution the distinction between mineral and rock particles is made. All Plutonic rocks are regarded as consisting essentially of silica or *silicates*, excepting that in the crystalline schists *carbonates* appear. The silica free minerals—apatite, magnetite, ilmenite, etc., are treated as accessory constituents. This exclusion of the latter group of minerals from a position of systematic importance is not discussed by Roth, but its evident result is that in certain rocks, *e. g.*, those rich in magnetite, the components do not have their natural and logical weight in classification.

Of the pre-Tertiary eruptive rocks, Roth makes, for convenience, three divisions:

I. Orthoclase rocks.
II. Plagioclase rocks.
III. Peridotites.

The first two of these groups should, logically, have been united systematically in the division of Feldspathic rocks, including all with appreciable content in feldspar, since the Peridotites are defined as free, or nearly free, from feldspar. The question of recognizing the quantitative relations of mineral constituents is not mentioned by Roth.

The silicate minerals are applied by Roth for the subdivision of the three main groups in the usual way, and by means of *structure* the granular, porphyritic, and glassy varieties are distinguished.

In the detailed treatment of Eruptive rocks, as in the arrangement of Crystalline schists, the Neptunic rocks and the Classes B and C, mentioned above, Roth's order of presentation and discussion can hardly be said to be systematic. It is an arrangement for convenience of description, not based upon the logical application of principles; and it is, therefore, not desirable to devote more space to its analysis in this review.

E. Kalkowsky, 1886.— A condensed text-book on rocks was published by E. Kalkowsky, in 1886, with the title *Elemente der Lithologie.*[1] For the primary division of rocks the author formulates an original criterion, and proposes two great classes:

I. "Anogene"—of which the material came to the place of rock formation from *below*.

II. "Katogene"—of which the material was derived from *above*.

These correspond closely to the eruptive and sedimentary divisions of other authors.

For the classification of the "Anogene" rocks Kalkowsky applies the following factors: (1) Chemical composition as represented in mineral composition; (2) the usual age distinction; (3) structure. He rejects genetic distinctions as unsuit-

[1] Heidelberg, 1886, pp. 316.

able. In detail Kalkowsky's scheme is similar in its results to that of Zirkel, but, as he does not define his smaller rock divisions, a further discussion of his arrangement seems unnecessary. The definitions are omitted, according to the author, because the student must learn to know the rocks by the study of named hand specimens and will, therefore, find out what they are without definitions.

J. J. Harris Teall, 1886, 1888.—The most extensive treatise on rocks thus far published in England is the descriptive work *British Petrography*, by J. J. Harris Teall, issued almost simultaneously with the second edition of Rosenbusch's *Massige Gesteine*. This work lays no claim to being a systematic petrography, and describes almost exclusively the igneous class; but from its scope a discussion of principles of rock classification was necessary, as explanatory of the arrangement actually used. Teall considers rocks so complex and indefinite in character that in the existing state of knowledge no true systematic arrangement is possible. His order of presentation is, in fact, one of convenience, and does not express his own views of the most natural basis of classification.

In discussion of principles, Teall points out that chemical composition, as the constant and primary character of igneous rocks, is the natural basis of classification and in accordance with the Bunsen law of two magmas. He, however, does not work out any new proposition to use chemical composition. The arrangement under which rocks are described is a mixture of the methods of Rosenbusch and Michel-Lévy. All igneous rocks are placed in seven groups, as follows:

A. Rocks composed of the ferro-magnesian minerals: olivine, enstatite, augite, hornblende, and biotite. Feldspar absent; or, if present, occurring only as an accessory constituent.

B. Rocks in which plagioclase is the dominating feldspathic constituent. Nepheline and leucite absent. Orthoclase is frequently present.

C. Rocks in which orthoclase is abundant. Plagioclase usually present. Nepheline and leucite absent.

D. Rocks containing nepheline or leucite; sometimes nepheline and leucite.

E. Rocks not included in any of the preceding groups.

F. Vitreous rocks.

G. Fragmental volcanic rocks.

It will be seen that this grouping is mainly mineralogical and does not express the quantitative element in any logical way. It practically recognizes the entrance of feldspar, in any amount above that of the undefined "accessory" rôle, as creating a large group of *feldspathic rocks*. The subdivision of these groups is first on some further mineral distinction and after that occurrence and texture enter combined into the system by distinguishing rocks of *granitic* from those of *trachytic* texture, using these terms in the sense of Fouqué and Michel-Lévy, and conceiving that the result is practically to separate *plutonic* or deep-seated from *volcanic* or effusive rocks. Age is not introduced as a factor.

Within the last twenty years several attempts have been made to apply, *in extenso*, the chemical composition of rocks for their classification. These attempts have been prompted by various motives. Some appear to have no really practical object, viewed from the petrographer's standpoint; others are connected with hypotheses of magmatic differentiation; and still others have been inspired by a realization of the complexity of the problem of a rational arrangement of rocks on the basis of their numerous and highly variable mineral constituents. It appears to the writer, however, that it may be fairly said of all these attempts that they are either not classifications of *rocks*, or that they are not actually *chemical* classifications.

Franz Schröckenstein, 1886, 1897.—Two peculiar attempts by Franz Schröckenstein, an Austrian writer, to discuss the chemical composition of silicate rocks, irrespective of their origin, and upon that basis to classify them, are mentioned here only for the sake of completeness, as these attempts have no direct bearing upon a logical system of rocks. The writer has seen only the more recent of the essays in question,[1] depending for the

[1] "Silicat-Gesteine und Meteorite," *Petrographisch-chemische Studie auf Grundlage des neuesten Standes der Wissenschaft bearbeitet.* Prag, 1897.

earlier one[1] upon the summary given by F. Loewinson-Lessing.[2]

Schröckenstein's view of igneous rocks will, on account of its fantastic imaginings, impress many a reader as belonging rather to the eighteenth, or a still earlier, century, than to the close of the nineteenth; and, although his propositions are of no consequence to petrography, the fact that they have been put forth at all, in the very last decade of the period in review, has a certain melancholy interest.

Schröckenstein considers the original crust of the earth to have been a *silicate of alumina*, probably with excess of silica. This simple primary magma is conceived to have been first rendered impure by meteoric showers, introducing lime, magnesia, and iron. At a later period the alkalies and water were precipitated from the atmosphere. The alkalies are considered as of very subordinate ("nebensachlich") importance and the chemical problem of rocks, as the author views it, is to compare the relative amounts of the original alumina silicate and the meteoric impurities. That is to say, *the author proposes classes according to the degree of adulteration of the original magma and orders according to the character of the adulterant.*

The method followed by Schröckenstein in comparing analyses of silicate rocks appears to be somewhat as follows:

First, magnetite is calculated out, as an *extraneous substance*, whenever the analysis is sufficiently modern, through determinations of both ferric and ferrous oxides, to give a basis for such calculation. When the analysis is inadequate and the iron is lumped under one or the other oxide, the result is accepted by the author and Fe_2O_3 is supposed to replace alumina or FeO is added to MgO and CaO. Not until magnetite is deducted does Schröckenstein consider that the real rock is under discussion. Inasmuch as he states that after deducting magnetite there is either no iron left or but one oxide appears, it is evident that the

[1] Ausflüge auf das Feld der Geologie," *Geologisch-chemische Studie der Silicatgesteine*, II Auflage, Wien, 1886.

[2] "Studien ueber die Eruptivgesteine," *Compte-Rendu, VII Cong. Géol. Internat.*, 1899, p. 196.

maximum possible amount of magnetite is deducted. The remainder is then calculated to 100. The analyses are not given in their original form.

The systematic plan of Schröckenstein consists, in his later publication, in establishing five classes of silicate rocks, according to the relations of Al_2O_3 to RO ($=CaO + MgO + FeO$) as shown by the *percentages* of the calculated remainder after deducting magnetite.

$$\text{I. } \frac{RO}{Al_2O_3} < \frac{1}{4}; \quad \text{II. } \frac{RO}{Al_2O_3} < \frac{1}{2} > \frac{1}{4}; \quad \text{III. } \frac{RO}{Al_2O_3} < \frac{3}{4} > \frac{1}{2};$$

$$\text{IV. } \frac{RO}{Al_2O_3} < \frac{1}{1} > \frac{3}{4}; \quad \text{V. } \frac{RO}{Al_2O_3} > \frac{1}{1}.$$

Two orders appear under each class according as lime or magnesia dominates.

Although Schröckenstein professes to use the latest information, as stated in the title of his recent publication, his results are based upon the discussion of 340 analyses, many of them old, while on the other hand no single one of the hundreds of analyses made in the laboratory of the United States Geological Survey, within the past twenty years, is utilized. Hundreds of European analyses of recent date are also ignored.

It seems unnecessary to give any further details concerning Schröckenstein's propositions. He is not actually treating rocks and his superficial considerations of chemical composition can have no bearing upon true petrographic system.

H. O. Lang, 1891.—An attempted arrangement of igneous rocks on a chemical basis by H. O. Lang,[1] in 1891, is founded on the idea that since the feldspars are the most important constituents of eruptive rocks, an appropriate and practical chemical basis of classification may be found in the relations of the bases potash, soda, and lime, the distinctive elements of the various species of feldspar. In one case Lang used the percentage

[1] "Versuch einer Ordnung der Eruptivgesteine nach ihrem chemischen Bestande," *Tscher. Min. Pet. Mitth.*, XII, 1891, p. 199.

"Das Mengenverhältniss von Calcium, Natrium, und Kalium als Vergleichungspunkt und Ordnungsmittel der Eruptivgesteine," *Bull. Soc. Belge de Géol.*, 1891, V, p. 123.

amounts of the oxides found by analysis, and in the other the amounts of the elements potassium, sodium, and calcium. Here again is the situation that only a part of some rocks is actually under discussion, and the result can be of no real value to petrography.

F. Loewinson-Lessing, 1890, 1897. In 1890 an attempt at a chemical classification of igneous rocks was made by F. Loewinson-Lessing,[1] based upon the quantitative relations of silica to the various oxides of the bases, grouped under R_2O, RO, and R_2O_3, as shown in *percentages* by bulk analysis. By means of empyrical formulæ the author thought to find a way of expressing regular relationships supposed to exist between the silica contents and the various oxide groups. Rocks exhibiting the following simple relationships were designated *types*, I to V being the principal ones, and VI to IX intermediate:

Acid Rocks
$$\text{I. } SiO_2 = 2(R_2O + RO) + R_2O_3 + Q \, .$$
$$\text{VI. } SiO_2 = \frac{3}{2}(R_2O + RO) + R_2O_3 + Q \, .$$

Neutral Rocks
$$\text{II. } SiO_2 = 2(R_2O + RO) + R_2O_3 \left(\text{II} = \frac{\text{I} + \text{IV}}{2}\right) .$$
$$\text{VII. } SiO_2 = \frac{3}{2}(R_2O + RO) + R_2O_3 \, .$$

Basic Rocks
$$\text{III. } SiO_2 = R_2O + RO + R_2O_3 \left(\text{III} = \frac{\text{II} + \text{IV}}{2}\right) .$$
$$\text{VIII. } SiO_2 = R_2O + RO + \frac{1}{2} R_2O_3 \left(\text{VIII} = \frac{\text{III} + \text{IV}}{2}\right) .$$

Ultra Basic Rocks
$$\text{IV. } SiO_2 = \text{or} < RO \, .$$
$$\text{IX. } SiO_2 = \frac{1}{2} RO \, .$$
$$\text{V. } SiO_2 = O \, .$$

Since percentages instead of molecular ratios were used, the simple relations here adopted have no real significance as expressing a regular connection between chemical and mineral composition. This fault was perceived by the author and cor-

[1] "Étude sur la composition chimique des roches éruptives," *Bull. Soc. Belge de Géol.*, 1890, IV, Mem., p. 221.

rected in the publication to be discussed below. These so-called types were assumed by Loewinson-Lessing to correspond more or less closely to certain commonly known rock groups.

The more elaborate discussion of the chemical relationships of igneous rocks by Loewinson-Lessing, presented to the International Geological Congress at St. Petersburg, in 1897, and published two years later in the *Compte-Rendu*, deserves somewhat fuller consideration.[1] A brief statement of the author's point of view is desirable before explaining the system proposed.

In reviewing the applicability of various factors in producing a rational system, Loewinson-Lessing asserts that the mineral composition of a rock is a function of its chemical composition. The exceptions to this rule admitted by him are of little importance. Then follows the further statement that the principle or characteristic of mineral composition as a basis of classification is faulty and unsatisfactory because it does not show the relative abundance of the minerals in the various rocks. That is, however, as it appears to the writer, not the fault of the *principle*, but of the manner in which it has been applied in existing systems. If mineral composition is a function of the chemical composition, it is just as capable of expressing the constitutional relations of rocks as the latter, if properly used. The real objection to its application in the quantitative way, necessary to this expression, is simply one of practicability. The problem is too complex.

As for his own system, Loewinson-Lessing starts from the idea that eruptive rocks may be considered as *silicate rocks* and classified as such. Whatever the facts as to predominance of silicates in these rocks may be, it seems to the writer that this conception is not complete as to its basis of fact, and is thus inadequate to serve as a means of classification. Further fundamental propositions enunciated by the author are that: (1) silicate rocks should be classified by the same artificial means as the silicates themselves; (2) while rocks are not stoichiometric

[1] F. LOEWINSON-LESSING, "Studien über die Eruptivgesteine," *Compte-Rendu de la VII session du Congrès Géologique International, Russie*, 1897, pp. 193–467.

compounds, they are not accidental mixtures; (3) one must consider the relative amounts of *all* oxides of bases to each other and to silica; (4) as silica is the dominant constituent it is proper to take it as the basis for the primary classification; (5) the next factor to be applied must be the contents in the three oxide groups, alkalies, alkaline earths, and the sesquioxides; (6) various single oxides may be used for further subdivisions. From this statement it might be supposed that a classification created by the successive use of the chemical factors named was to be set up by Loewinson-Lessing, and such an arrangement of magmas would have claim to being a chemical classification. But the author does not do that, as we shall see.

The actual system proposed by Loewinson-Lessing is to use the silica contents for the formation of four general groups: (1) Acid rocks; (2) Neutral rocks; (3) Basic rocks; (4) Ultra-basic rocks.

The second division is obtained by taking a certain number of analyses representing known rock families (established on the unsatisfactory basis of mineral composition) and determining the *mean* of these analyses, which is then set up as the composition of a rock *type*, and its formula and coefficient of acidity are ascertained.

It is clear that the grist of this mill depends entirely upon what is put into the hopper. It is not a chemical classification but a chemical *characterization* of mineralogical rock groups arbitrarily selected by the author. It will, of course, be possible to secure means corresponding to any formula desired as a type, and the rocks thus having typical position could be adopted as centerpoints of groups or families. For the ordinary range of rocks these types would often coincide with recognized rocks, assigned certain names in existing systems, and these names might then be given by redefinition to the families thus indicated. But what would be the purpose of such a scheme? It could not express the existing relations between the mineral composition of the rock and the chemical constitution of the magma.

A. Osann, 1900, 1901.—A further attempt to utilize chemical composition as a factor in the classification of igneous rocks was made by A. Osann in the closing year of the century. Under the title "Versuch einer chemischen classification der Eruptivgesteine"[1] Osann essays to use chemical composition as a supplement to mineral and textural characters, by establishing various chemical types within rock families formed upon the Rosenbusch system. The author accepts the classes of deep-seated, dike and effusive rocks, in the Rosenbusch sense, and the vaguely defined families established upon mineral composition. Realizing that by this latter factor, as currently applied, the relative abundance of the minerals is not sufficiently taken into account, Osann attempts to bring out quantitative relations, within the families, by establishing certain types upon the basis of chemical composition.[2]

It is clear that if the quantitative element was not sufficiently expressed in forming the families discussed by Osann, he fails to remedy the defect. A logical subdivision of the families on a chemical basis would principally serve to point out the defects in this respect, and would really weaken rather than strengthen the system as a whole.

But the "types" set up by Osann are in no sense systematic divisions of the families. The "type" of this author is simply a chosen well-analyzed rock, differing in chemical composition from other rocks within its family, according to the adopted method of comparison. To a type thus established are referred other rocks of nearly identical chemical characters. But the types bear no definite relation to each other or to the family.

[1] *Tschermak's Min. und petr. Mittheilungen*, Bd. XIX, 1900, pp. 351–469, and Bd. XX, 1901, pp. 399–558.

[2] The author's standpoint may be sufficiently understood from the following statement: "Der Hauptmissstand der mineralogisch-structurellen Classification liegt darin, dass dem relativen Mengenverhältniss der wesentlichen Gemengtheile zu wenig Bedeutung zuerkannt wird, und es wird gerade die Hauptaufgabe der chemischen sein, in dieser Richtung ergänzend und vertiefend zu wirken." "So kann es sich bei dem hier unternommenen Versuch ebenfalls nur um ein künstliches System handeln, welches in erster Linie dazu bestimmt ist, das mineralogisch-structurelle zu ergänzen." *Ibid*, Bd. XIX, pp. 351–352.

They merely serve to show the chemical range found within the families so far as Osann's examination extends.

From the above statement it would appear that Osann has not, in reality, proposed a chemical classification in the systematic sense, and hence it is not desirable to enter further into the analysis of this elaborate discussion of the chemical varieties represented within the families of the Rosenbusch system.

This discussion of petrographic systems proposed during the nineteenth century will close with a review of three attempts to bring all known rocks into orderly arrangement. Not that the authors think to have formulated natural or logical systems, for that is expressly disclaimed by them. Yet in presenting these comprehensive arrangements of rocks, according to the light of the last decade of the century, these authors define and illustrate in a most effective way the present condition of systematic petrography.

Ferdinand Zirkel, 1893, 1894.—The second edition of Zirkel's *Lehrbuch der Petrographie* is the most comprehensive and complete description of all known rocks ever published, and it therefore represents the present status of the systematic science as a whole, better than any other work, and hence deserves careful consideration. But the fact staring the student in the face is that systematic petrography is still very largely an arrangement for convenience of description, and is not, in its entirety, a logical expression of relationships. Within the division of igneous rocks there is at least some attempt at system, but the other rocks confessedly defy logical treatment by any method as yet proposed.

The primary division of all rocks is on general geological grounds into four groups:

I. Igneous rocks—"Massige, eruptive Erstarrungsgesteine."
II. Crystalline schists.
III. Sedimentary crystalline rocks (not clastic.)
IV. Clastic rocks.

This division is clearly based on geological considerations,

and is chosen in place of the primary arrangement of the first edition because, as Zirkel points out, of inconsistencies and unnatural associations which resulted, some of which have been mentioned in this review. Contact metamorphic rocks are treated in connection with the igneous rocks which produced them. Fragmental igneous rocks are placed with the clastics.

In the systematic classification of igneous rocks Zirkel uses the bases of arrangement in the following order: (1) mineral composition; (2) structure; (3) age. The availability of chemical composition, alone, or in expressed combination with mineral constitution, is not discussed. The method of applying mineral composition for the classification of igneous rocks is that commonly used. Concerning this Zirkel remarks:

> In a mineralogical arrangement of massive rocks the following considerations are at present determinative: In the great majority of these rocks feldspars and other silicates resembling feldspars (such as nephelite, leucite, melilite) play the chief rôle, and therefore it is most natural to base the classification of such rocks upon the nature of these minerals, in accordance with existing nomenclature.[1]

This procedure results in placing *feldspar- or feldspathoid-bearing* rocks in one large group opposed to *feldspar-free* rocks. Whatever the facts may be as to the relative quantitative importance of different minerals in igneous rocks, it is clearly arbitrary to concede to any mineral the "principal rôle" where it is far subordinate to others. The result is a qualitative expression of mineral composition, bringing chemically unlike rocks together in many divisions.

In the descriptive portion of the *Lehrbuch*, igneous rocks are grouped under seven heads:

I. Rocks with alkali feldspar and quartz or excess of silica.

II. Rocks with alkali feldspar, without quartz or excess of silica, without nephelite or leucite.

[1] Für die mineralogische Gruppirung der Massengesteine sind zur Zeit folgende Erwägungen maassgebend: In der weitaus allergrössten Mehrzahl derselben spielen Feldspathe und andere feldspathähnliche Silicate (wie Nephelin, Leucit, Melilith) eine Hauptrolle und so scheint es am natürlichsten, die Classification der hierher gehörigen Gesteine auf die Natur dieser Mineralien zu begründen, was zugleich der bestehenden Nomenclatur entspricht. — *Petrographie*, Band I, p. 832.

III. Rocks with alkali feldspar, without quartz or excess of silica, with nephelite (haüynite) or leucite.

IV. Rocks with lime-soda feldspar, without nephelite or leucite.

V. Rocks with lime-soda feldspar and nephelite or leucite.

VI. Rocks without true feldspars, but with nephelite, leucite, or melilite.

VII. Rocks without either feldspars or feldspathoid.

Structure and geological age are applied by Zirkel under each of the mineralogical groups, as follows:

Granular rocks.
  (No distinctions by age.)
Porphyritic and glassy rocks.
  Pre-Tertiary.
  Tertiary and recent.

The structural distinction is clearly in fact between (1) granular and (2) non-granular, the range in structure within the second division being by no means covered by the two terms porphyritic and glassy.

The use of age as a factor in classification of "porphyritic and glassy rocks" while it is not applied to the granular rocks is apparently more a recognition of the usage of the time, by which a duplicate set of terms has been provided for effusive rocks, than of any definite principle. The task of reconstructing the nomenclature of the science is still one from which the systematic petrographer shrinks.

The group of the *crystalline schists* established by Zirkel is not founded upon definitely stated principles, and is therefore not a systematic group. It is defined by enumeration of things belonging in it or excluded from it, and must be treated as a convenient expedient for purposes of rock description. But although this is true the crystalline schist group of Zirkel is no more unsystematic than the assemblages of other petrographers given the same name. It is then germane to the present discussion to state the actual course adopted in the *Lehrbuch*.

Zirkel includes in his group of the crystalline schists, and as its most important element, the pre-sedimentary gneisses, schists, etc., which cannot be inferred from their attitude to other rocks to be of igneous origin. Included with these are all rocks of the

same texture and composition demonstrably derived from sediments or occurring intercalated in the sedimentary series but not clearly of igneous origin. Excluded from the group under discussion are the primarily banded igneous rocks and the metamorphic derivatives of igneous rocks whenever that origin can be established, and whatever the process of change may have been. In other words the group includes the rocks below the oldest known sediments so far as they are not visibly eruptive or igneous and all later rocks of the same characters derived from sediments or of unknown origin.

This group then has nothing in texture or composition to distinguish it. Neither of the elements of the name has any restrictive significance. The group is geologically homogeneous only in case the schists of unknown origin are actually derived from sediments. If, as many suppose, a large proportion of the Archean gneisses, etc., represent igneous masses, metamorphosed or not, the group is not only heterogeneous from the genetic standpoint but causes the separation of identical things.

In the subdivision of the crystalline schists mineral composition is applied, the predominant constituent causing the reference of a rock to a certain group. The terms gneiss and schist are not defined.

The group of *crystalline, or non-clastic sedimentary rocks*, is heterogeneous in constitution as is apparent from a partial list of the rocks referred to it : ice, cryolite, limestone, opal, quartzite, porphyroid, iron ores, coals, diatomaceous earth. That such a group lacks the unity required in a systematic division, and that its descriptive name by no means covers the case, is apparent at once. It is confessedly a grouping for convenience only, and embraces, in fact, the remaining rocks after the other three have been established.

H. Rosenbusch, 1898.— A comprehensive discussion of rocks was issued in 1898, by H. Rosenbusch, entitled, *Die Elemente der Gesteinslehre.*[1] Although much less detailed than the *Lehrbuch* of Zirkel, this work is of much interest as expressing the views of

[1] Stuttgart, 1898, pp. 546 + 4.

one of the great German masters, almost at the close of the century.

Rosenbusch's primary division of rocks is into four great classes :

I. Eruptive rocks (" Eruptivgesteine ").
II. Stratified rocks (" Die schichtigen Gesteine ").
III. Crystalline schists.
III. Primary crust of the earth (" Erste Erstarrungskruste ").

Concerning the first class, it is to be noted that Rosenbusch drops the term "massig," used for twenty-five years, as less appropriate—" weniger passend villeicht "—than *Eruptive*. In the further treatment of eruptive rocks Rosenbusch does not depart from the principles and methods of the last edition of the "*Physiographie der massigen Gesteine*," and there is, therefore, no occasion to repeat the analysis of that work already given.

The stratified rocks of Rosenbusch form a class under the general idea expressed by Lossen. It is pointed out by Rosenbusch that the character of the materials of stratified rocks is not so intimately related to the essence (" *Wesen* ") of the mass as with eruptive rocks, and hence there is no corresponding firm basis for their classification.

Stratified rocks are divided into seven families, as follows:

1. *Precipitates*—including rock salt, gypsum, anhydrite, barite, etc.
2. *Psephites and Psammites* or clastic rocks.
3. *Siliceous rocks*—not clastic, partly chemical deposits, partly organic, partly of undetermined origin, *e. g.*, lydite, diatomaceous earth, sinter, etc.
4. *Carbonate rocks*—including limestone, dolomite, and impure calcareous rocks, loess, etc.
5. *Iron rocks*—including spathic iron, spherosiderite, brown hematite, bog ore, etc.
6. *Clay rocks*—including clay, clay-slate, phyllite, etc.
7. *Porphyroid.*

Appendix. Coals, etc.

In this arrangement Rosenbusch attempts no logical construction of anything which can be called a system. As he frankly admits, the porphyroids are metamorphic rocks, often associated with the crystalline schists, and as they were not

derived from sediments it is incorrect to place them in the stratified class. In the necessity for placing coals and other carbonaceous rocks in an *appendix* is further evidence that the arrangement under discussion is inadequate.

The Crystalline Schists are defined by Rosenbusch as alteration products of eruptive or sedimentary rocks. Both dynamic and contact metamorphism are recognized as effective in producing them. Rosenbusch further asserts that the changes have been entirely structural and molecular, and not chemical, hence by quantitative analysis of a metamorphic or crystalline schist one may arrive at a knowledge of the composition of the original rock, eruptive or sedimentary, from which that schist was derived. The designation *metamorphic rocks* is acknowledged to be appropriate.

The Crystalline Schists are treated under the following heads: (1) Gneiss, (2) Mica schist, (3) Talc schist, (4) Chlorite schist, (5) Amphibole and pyroxene rocks, (6) Serpentine, (7) Lime series, (8) Magnesian series, (9) Iron series, (10) Emery.

Concerning these groups Rosenbusch remarks:

> In most of these large groups of the Crystalline Schists, which are held together mainly through mineral composition, there are united rocks of fundamentally different genesis. Therefore they are not natural but rather artificial series. For the replacement of these artificial groups by natural ones there is lacking, at the present time, both necessary breadth of experience and maturity of judgment, from which the need for reform in various directions is evident.[1]

Believing that the natural classification of metamorphic rocks must develop by the historical method, with the increase of knowledge, Rosenbusch proposes, as a step in the desired direction, to apply the prefix *ortho* to the names of gneisses derived

[1] In den meisten dieser grossen Gruppen von Krystallinischen Schiefern, welche lediglich durch gleichen oder ähnlichen Mineralbestand zusammengehalten werden, sind genetisch grundverschiedene Gesteine zusammengefasst. Daher sind sie nicht natürliche sondern künstliche Reihen. Zur Umgestaltung dieser künstlichen Gruppen in natürliche fehlt zur Zeit noch einerseits die erforderliche Breite der Erfahrung, andererseits die Reife des Urtheils und damit das Bedürfniss nach Reform in weiteren Kreisen. —*Elemente*, p. 461.

from eruptive rocks, and *para* to those derived from sediments. The enumerated divisions of Crystalline Schists are not defined in a systematic manner, and even the terms *gneiss* and *schist* are given no definite meaning.

The fourth class of rocks advocated by Rosenbusch, on genetic grounds, *the original crustal rocks*, is considered by him as not certainly represented by any known rocks. But it appears to him probable that they possess the habit of the crystalline schists.

Johannes Walther, 1897.—An outline of a general classification of rocks upon a logical and consequent basis was presented to the Seventh International Congress of Geologists in St. Petersburg, in 1897, by Johannes Walther.[1] Although but an outline of a system this proposition deserves attention as the most consistent effort yet made to formulate a system of petrography co-ordinate in method for different classes of rocks.

Walther starts from the consideration that the growth of petrographic system in recent years has been very one-sided, a fact recognized by all. He believes that a natural arrangement of igneous rocks has been provided by petrographers of the modern school, while sedimentary and metamorphic rocks are still arranged upon old and partly incorrect bases. Aiming to secure a logical system, Walther formulates the following principles which he thinks should be observed in the classification of rocks:

I. The petrogenesis of recent deposits and the direct observation of actual processes are the fundamental principles of classification.

II. Every older rock has *primary* characters given it at its formation, and secondary ones derived by *diagenesis* or *metamorphosis*.

III. The derived characters may so change the type of the rock as to become "essential," while the primary characters become "accessory."

IV. In spite of this last condition only the primary characters should determine the principal groups of petrographic system.

V. Next to the primary lithologic characters the primary form of occurrence has a classificatory value. There must be distinguished, therefore, Unstratified, Stratified, and Dike rocks.

[1] "Congrès géologique international," *Compte-Rendu de la VII session, St. Pétersbourg, 1897*, p. 9 (issued in 1899).

VI. The characters derived by chemical diagenesis, or by contact and pressure metamorphism, serve for distinction of lesser groups.

VII. The altered rocks are to be placed with their original types.

The system proposed by Walther, in accordance with the stated rules, is in outline the following:

I. Mechanical Rocks. Composed of older rock fragments; divided by form and size of the fragments into 5 subgroups:
  1. Breccias: (*a*) Unstratified; (*b*) Stratified; (*c*) Dike form.
  2. Conglomerates: (*a*) Stream deposits; (*b*) Delta deposits; (*c*) Strand deposits.
  3. Moraines.
  4. Psammites — sands, more or less sorted: (*a*) Quartzose sandstone; (*b*) Arkose; (*c*) Olivine sands; (*d*) Iron ore sands, etc.
  5. Pelites — of minute particles: (*a*) Unstratified; (*b*) Stratified — fresh-water; (*c*) Stratified — marine.

II. Chemical rocks. Precipitates or sublimates.
  1. Calcium carbonate.
  2. Calcium sulphate.
  3. Sodium chloride.
  4. Haloid Salts ("Abraumsalze").
  5. Silica.
  6. Carbon.
  7. Ores.

Further divisions are made by occurrence — as Stratified, Unstratified, or in Dikes.

III. Organic rocks. Formed of the remains of animals or plants.
  1. Limestone: (*a*) Unstratified — Reef limestone; (*b*) Stratified — derived from plants (algæ); (*c*) Stratified — derived from animals.
  2. Silica: (*a*) Diatomaceous earth and land plants; (*b*) Diatomaceous earth with marine fossils; (*c*) Radiolarian earth.

IV. Volcanic rocks — Consolidated magmas.
  1. Lavas — Compact rocks: (*a*) Unstratified — deep-seated rocks; (*b*) Stratified — Effusive rocks; (*c*) Dike rocks.
  2. Tuffs — Magmas consolidated in small fragments: (*a*) Unstratified, in streams, not sorted; (*b*) Unstratified, subaqueous accumulations near vent — water tuffs; (*c*) Stratified, sorted according to specific gravity; originally inclined; traversed by dikes — tuffs about a land volcano; dry tuffs; (*d*) Stratified, alternating with marine deposits, without dikes; tuffs of sedimentation; (*e*) tuff dikes or chimneys.

In connection with these primary rocks the author mentions,

as examples, many of the forms derived from them by diagenesis or metamorphosis, but does not outline the system for discriminating and naming these alteration products. Some of the metamorphic rocks, such as gneiss and mica schist, may be formed from several primary rocks.

The proposition made by Walther is manifestly rather the work of a geologist than of a petrographer (as was pointed out by Brögger in discussion, when it was presented to the Congress). Like many discussions of principles concerned in the systematic problem, it is not sufficiently worked out to show a practical result, and does not fully test the adaptability of the chosen factors for petrographic system. But it seems to the writer that in this renewing of effort to treat the non-igneous rocks in logical systematic manner lies ground for hope that something more than an arrangement for convenience may develop during the early years of the twentieth century.

Returning to a consideration of the principles adopted by Walther, it may be remarked that the first one would be excellent if the processes of rock formation were all open to examination. Unfortunately, they are not so, in all cases. Many igneous rocks and nearly all of metamorphic origin have resulted from processes we cannot see in operation and can only imperfectly imitate in experiment. The fourth rule is not a necessary consequence of the facts stated under II and III. It is open to argument whether the processes which originally produced a rock are more deserving of recognition in petrographic system than the processes which have greatly or entirely changed the characters and perhaps even the composition of the original mass, making the rock now accessible to our studies.

As to rule V it can hardly be said to warrant the application made of it, in establishing the three divisions of unstratified, stratified, and dike forms for all kinds of rocks. Where the relations expressed by these terms have some genetic connection with the properties of the rocks they may perhaps be adaptable to classificatory purposes, but there is no logical reason for applying this principle in unqualified form.

The system of Walther seems specially intended to express the changes rocks undergo rather than their characters as now seen, and it is not apparent that the author had in mind the apt and logical analysis of the broad science of rocks which we owe to Naumann.

That the general treatment proposed by Walther for igneous rocks, in naming them volcanic, and making the primary division into unstratified, stratified and dike rocks, has many objections will be sufficiently clear from the preceding discussions of this review. The same is true of the assumption that there exists a satisfactory system for the classification of igneous rocks. The definition of tuffs as composed of magma consolidated in small particles certainly applies to but a small part of the pyroclastic deposits.

SUMMARY.

The science of petrography, the systematic and descriptive science of rocks, was first fairly outlined by von Leonhard (1823) and Brongniart (1827) through the distinction between the rock and the geological terrane, and the setting up of logical classifications for the former. Neither of these masters gave the science a name.

The systems of von Leonhard and Brongniart necessarily used the condition of ignorance concerning the character of many rocks as a ground for classification. With the increase of knowledge of rocks there have been many attempts to apply new information to systematic purposes. Since both the geological relations and the properties of rocks are highly varied many unlike systems have been proposed during the century, expressing individual opinions as to the relative importance or adaptability of principles for the end in view. Up to the present time, however, no comprehensive classification of rocks has been proposed which even pretends to be natural or logically consistent in all its parts.

When we view past petrographic systems, to judge as to how far they possess natural or artificial features, it is first of all to be noted that the system of Cordier is practically the only one starting from the conception that rock species are natural

units and that classification consists in the grouping by more or less artificial means of these fundamental units. Others have sought to make the system of rocks in some degree natural by applying geological factors of occurrence, or genesis, as bases of classification. The view is apparently held by some that in time there will be a comprehensive system expressing all important relations of rocks and that until that result is achieved all arrangements must be regarded as unsatisfactory and temporary.

It appears to the writer that those who hold this attractive and apparently philosophical view may not have in mind the distinction between the formal unit and the rock substance of that unit, or that distinction between the various cross-classifications of petrology and the one system of petrography, with which the nomenclature is specially connected.[1] The belief expressed by Lossen that "geological relations must be recognized as petrographical relations" and the assertion by Rosenbusch that "petrography is an historical science" illustrate this point.

If the system of petrography is to be hierarchical, as the writer believes it should be, the natural element in system is to be provided for in the judicious selection of broad geological factors so related to important characters of rocks that the completed system in the construction of which those characters have been used, will have a logical and appropriate co-ordination and sequence of parts. That this aim has not controlled in the past is evident from the following partial list of designations given to the rocks which are actually consolidation products of magmas: "Composite, crystalline-granular, and porphyritic" (Zirkel); "Non-clastic, composite, massive" (Zirkel); "Composite-simple" (von Lasaulx); Unstratified, Anogene, Massive, Plutonic, Volcanic, Eruptive, Igneous. Here are expressed a number of natural relations, to be recognized in the proper place, but only the last term refers directly to the relation most appropriate for petrographic system. It was not the fact that eruptive force was

[1] See "The geological versus the petrographical classification of rocks," by WHITMAN CROSS, JOUR. GEOL., Vol. VI, p. 79, 1898.

exerted to bring molten magmas to the sites of the rocks we study, but the fact of the molten condition which gave its stamp of common characters to the products of consolidation.

Arbitrary steps are necessary in the classification of such objects as rocks, exhibiting gradations in all directions. But that fact does not justify such artificial systems as many of those which have been reviewed. Among the most distinctly artificial systems are those of Cordier, Senft, and von Lasaulx; but scarcely less so, as regards igneous rocks, are those which, while using chemical or mineral composition as the basis of arrangement, use only a portion of the mass. For examples: some of the chemical classifications take only certain components into account; Fouqué and Michel-Lévy classify igneous rocks by the character of that variable portion of the magmas consolidating during the second period; Rosenbusch uses the phenocrysts only, in certain parts of his system.

The fundamental requirement that systems should be logical in construction, with consistent and consequent application of principles adopted, has been so commonly disregarded that a summary of instances in point seems unnecessary. Some of the most widely used systems of today are notably illogical as to criteria, as has been pointed out.

One of the most serious defects of modern classifications of igneous rocks is a matter of bad logic, and to this defect the writer wishes to allude once more. It is commonly admitted that the chemical composition of these rocks is their most fundamental characteristic, and many authors would apparently be glad to apply this character in classification. It is generally stated, however, that the chemical is represented by the mineral composition, and as the minerals are so prominent it is convenient to use them in system. But with no further discussion it has been the universal plan to use the minerals in so limited a qualitative way that they do not in fact express chemical composition except in a most crude and inadequate manner. This procedure is purely and simply illogical, if the intention be to represent chemical composition by the minerals of the rock.

That some factors have been introduced into classification in a manner that is quite unscientific seems plain. The age distinction is one of the factors thus abused. It has long been known that no general distinction separated pre-Tertiary and Tertiary igneous rocks. It may be that the average chemical composition of magmas erupted in successive ages has undergone some change; but neither the character of the change, nor, least of all, any special connection with the particular time limit in question, has been established. The assumption that igneous rock textures, such as the granular, porphyritic, or vitreous, are functions of geological form or place of occurrence, is known to be contrary to the facts displayed by the rocks. Both of these assumptions have been and are now used in rock classifications.

Stability of system is certainly desirable, within the bounds of reason. But it is also self-evident that a system of artificial character, in which the subjective element is dominant, can be permanent only by universal consent of petrographers, and such consent is not to be expected. It is a matter of experience that genetic theories have made systems into which they have been introduced very unstable and impossible of general adoption. The danger of using hypotheses in classification has been well characterized by von Cotta, somewhat as follows: Geology is a particularly alluring field for premature attempts at the explanation of imperfectly understood facts; indeed, such attempts are almost unavoidable in the study of this science. When one considers hypotheses simply as such, *i. e.*, as stimulants toward their possible demonstration, then they are not harmful; the danger lies therein that one may believe them already proven and rest contented.[1]

The danger pointed out by von Cotta has been illustrated in the classification of igneous rocks by such able men as von Richthofen, King, and Rosenbusch. As regards the interior of the earth, whence the molten magmas come, we cannot as yet be sure that what we regard as a law today may not be relegated to the status of a theory or even of an hypothesis tomorrow.

[1] B. VON COTTA, *Gesteinslehre*, 2d ed., 1862, p. vi.

The genetic theory has its proper field of great usefulness in the department of petrology dealing with petrogenesis. Ultimately we may hope and expect that genetic relations of igneous rocks may be available for a more natural classification than is now feasible.

Any system of classification should be broad and thorough enough to include all the objects which it professes to deal with. But the authors of many systems outlined in this review have been obliged to resort to the expedient of *appendices* to bring in rocks not otherwise provided for. Such a necessity is, at once, evidence of the inadequacy of the criteria guiding the authors of such systems.

Even in the class of igneous rocks, propositions for chemical and mineral classifications do not fully recognize the systematic importance of some of the relatively rare constituents. Chemical systems which consider all igneous rocks as mixtures of silicates, or reject magnetite as extraneous, are not comprehensive. Similarly, the schemes which do not provide for the due recognition of titanium minerals, corundum, apatite, sulphides, etc., as important constituents in some cases, are inadequate, even for present uses, and certainly do not provide for future needs which can be clearly foreseen.

In conclusion, the status of systematic petrography at the close of the nineteenth century may be summarized as follows:

1. There is as yet no comprehensive and properly systematic classification of all rocks. All so-called systems exhibit portions in which the rocks are treated in an unsystematic manner, for convenience of description and discussion. The grand divisions are not treated by similarly logical and definite methods.

2. Rocks of igneous origin have been much more thoroughly investigated than others and they have received correspondingly more definite and systematic classification. The factors used in systematic construction pertain to genesis, age, and characters.

a. The origin of the great range in chemical composition exhibited by igneous magmas, expressed in theories of magmatic differentiation, is an underlying factor of much importance in

the system of Rosenbusch, and is also seen in the desire to recognize consanguinity of the magmas of petrographic provinces, as partially worked out by Iddings and Brögger. The availability of such factors in petrographic system is doubted by many authorities.

b. While the distinction of older and younger series of rocks through different sets of names is still found in the German and French systems there is practical unanimity of opinion that the real differences between the rocks are much less fundamental than was supposed. In America, Great Britain, and elsewhere, this distinction is held to be unwarranted.

c. The chemical and mineral composition of igneous rocks and their textures are characters used as means of classification in present systems. Chemical composition *per se* is used, but only by considering a portion of some rocks, and hence fails to provide an adequate system. The broad chemical divisions used by some authors are vague and overlapping.

Mineral composition is commonly assumed to represent the fundamental chemical constitution and to be, therefore, a convenient and practicable means of expressing the latter. In practice the qualitative method of applying mineral composition in existing systems destroys its effectiveness as expressing chemical composition.

Structure is variously used in present systems. It is acknowledged to be the product of conditions, and not dependent in marked degree upon mineral development. When applied as a primary factor in classification (as by Rosenbusch) it separates things which are similar in more fundamental characters, and on this ground some authorities believe that structure should be applied in classification after the other characters named.

3. The rocks which have formed upon the surface of the earth by the destruction of older rocks may be viewed from so many standpoints, as regards the origin of materials, agencies of transportation, relations to the earth or to other rocks, characters of materials, and processes of induration, that no consistent arrangement of these objects, deserving the name of a petro-

graphic system, has been proposed. In the existing arrangements the confusion of correlating various cross-classifications into one whole is quite evident.

4. Metamorphic rocks, including all such in which the derived characters are more prominent than the original ones, defy systematic treatment at the present time. Since they have been formed from all kinds of original rocks, by many different processes, and at many sites in the earth's mass, there are many standpoints from which they may be considered, and their classification is a complex problem. Among the facts most difficult to recognize in system are the close resemblance or identity of metamorphic products from originally different rocks, and the similar correspondence between certain secondary and primary rocks. The proposition of Walther to classify all metamorphics with the masses from which they were derived is thus impracticable at the present time, even if it be thought desirable. In relation to this class of rocks systematic petrography is in the condition that its arrangements are tentative, awaiting new knowledge concerning the genesis and essential characters of the objects.

The review of the development of systematic petrography given in the preceding pages has been mainly a discussion of comparatively comprehensive arrangements or systems which have been proposed. It is, of course, true that these systems are but correlations of ideas from many sources, and a complete history of the subject would give to important discoveries of fact and to critical or creative suggestions their due weight in influencing the development of systems. But such influence is difficult to trace, and to have attempted such a history would have involved the expenditure of much more time than the writer could devote to the subject. For this reason a large number of important essays, bearing upon certain features of classification or devoted to discussion of principles, have been left unnoticed because they were not accompanied by general

systematic propositions. Among the essays thus disregarded are notable ones by Rosenbusch, Brögger, Becke, Michel-Lévy, Teall, Iddings, Spurr, Turner, and many others.

The telling effect of searching investigations touching controverted points of fundamental significance and of the judicial remarks of those who have carried out such studies is often much greater than either author or reader is aware. In the course of time the influence exerted by a succession of investigations becomes evident in some proposition for the revision of classification. Petrography has thus come to its present condition by a steady natural evolution, and its future growth must undoubtedly follow the same course.

WHITMAN CROSS.